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Article

A Fuzzy MCDM Model of Supplier Selection in Supply Chain Management

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Abstract: According to a new study by the International Labor Organization (ILO), the COVID-19 pandemic has had a strong impact on the garment industry in the Asia-Pacific region. A sharp drop in retail sales in key export markets has affected workers and businesses across supply chains. To ensure the effectiveness and efficiency of garment supply chain, choosing a sustainable supplier should be a main concern of all businesses. The supplier selection problem in garment industry involves multiple quantitative and qualitative criteria. There have been many research and literatures about the development and application of Multicriteria Decision Making (MCDM) models in solving decision-making problems in different industry sectors such as supplier selection or investment assessment. Many different MCDM models have been introduced over the years, and each model is uniquely dedicated into solving a particular problem. There is very little MCDM models incorporated with fuzzy set theory to support decision makers with decision-making problem in uncertain environments. This paper introduces a Fuzzy MCDM-based approach to the problem by utilizing Fuzzy-Analytic Hierarchical Process (FAHP) and Weighted Aggregated Sum Product Assessment (WASPAS) methods to support the decision makers. The aim of the paper is developing a decision-making tool that supports the decision maker in deciding the suitable supplier in garment industry under fuzzy environment. The proposed MCDM model is applied to a real-world case study to demonstrate the application steps of the model as well as its feasibility. The model assisted in successfully its proposed goals that resulted in an optimal supplier in garment industry.

Keywords: Fuzzy theory; multi-criteria decision making model; garment industry; sustainability

1 Introduction

The garment industry has been a growing industry due to the increase of demand for garment products. From the unpredictability of the demand for garment products since some may considered it as a commodity, it is very important that the supply chains of garment products remain at a strong consistency. There are many factors that could affect the demand of garment products such as the color of the apparel [1], the type of fabric (rib and single knit fabric) [2], competition amongst other garment companies, social media marketing, and, importantly, supplier issues [3]. As popular garment companies such as Zara and H&M have been studied globally for their supply chains and how they are able to meet such high demand satisfaction, it is undeniable that the supplier selection process for the garment industry it crucial for its survival [4].

The supplier selection can happen at any stage of the supply chain. Some garment businesses seek an overseas supplier of raw materials that ensures the global quality standard. On the other hand, garment companies seek outsource or third parties in order to subcontract the production process of their products. The supplier selection process for subcontracting can be referred to in Fig. 1 (RFQ being the Request for Quote in order for suppliers can bargain and compete of the suitable pricing for the contractors) [5].

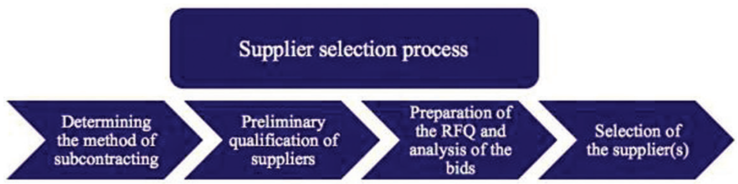

Figure 1: Supplier selection process [5]

With such a huge pool of suppliers available globally, there are many factors that helps businesses determine the best choice of suppliers such as geographical, pricing, competition, quality, and many more as referenced by Karami et al. [6]. Therefore, Multi-criteria Decision Making (MCDM) methods have been continuously studied as these factors turn into criteria for businesses as a decision maker role when deciding the best supplier for their companies. Popular MCDM methods such as Technique for Order Preference Similarity to Ideal Solution (TOPSIS), Fuzzy TOPSIS, Analytical Hierarchy Process (AHP), Fuzzy AHP, Data Envelopment Analysis (DEA), and Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) [7–10], have continued to show their strengths and weaknesses into solving the supplier selection problem for decision makers depending on the nature of the criteria based on qualitative or quantitative behaviors. The paper applies a real case study that requires solving a similar supplier selection problem that utilized the FAHP and Weighted Aggregated Sum Product Assessment (WASPAS) processes in order to determine the most suitable supplier.

2 Literature Review

In the past decades, many researchers have studied the application of MCDM methods in solving decision-making problems in various industries [11–18]. In many cases, MCDM models utilized fuzzy sets theory to solve decision making problems that involved qualitative criteria and information [19–23].

There have been many literatures regarding the application of MCDM techniques in solving location and supplier selection problems for multiple industries. Rao et al. [24] approached the City Logistics Center location selection with a fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) based MCDM model. The proposed model used in the aforementioned paper considered the problem under a sustainability perspective and included economic, environmental, and social criteria. Guneri et al. [25] developed an MCDM model based on fuzzy Analytical Network Process (ANP) method to solve a shipyard location selection problem. The approach combined fuzzy set theory in order to help the model deal with the uncertainty of the decision-making environment. Choudhury et al. [26]

introduced a novel MCDM based approach to solve a surface water treatment plant location selection problem. The model utilized Sinusoidal Analytic Hierarchy Process (SAHP) to calculate the weighting of relevant selection criteria and stepwise forward regression method to determine the ranking of the potential alternatives regarding sustainability. Tadić et al. [27] developed a hybrid grey MCDM model to support the dry port terminal location evaluation process. The proposed model is based on Analytical Hierarchy Process (AHP) and Combinative Distance-based Assessment (CODAS) methods in a grey environment. Karaşan et al. [28] extended classical MCDM methods (DEMATEL, AHP and TOPSIS) with Intuitionistic Fuzzy Sets (IFSs) to solve the vehicles charging stations location selection problem. The proposed model was verified by applying into a real-world case study in Turkey.

MCDM methods are also frequently applied to solve decision-making problems specifically renewable energy development projects. Solangi et al. [29] developed a hybrid MCDM model, based on AHP and Fuzzy TOPSIS methods, in order to solve a wind power plant location selection. The proposed model is applied to determine an optimal wind plant location in the Southeastern region of Pakistan. Villacreses et al. [30] applied the Ordered Weighted Averaging (OWA) method in combination with Geographic Information Systems (GIS) to create a decision support system for the sustainable wind energy plant location selection. The model was applied to solve a wind farm location selection problem in Ecuador. Mostafaeipour et al. [31] combined the Stepwise Weight Assessment Ratio Analysis (SWARA) and the Additive Ratio Assessment (ARAS) methods to solve the geothermal project location selection problem in Afghanistan. The proposed model also compared other MCDM methods such as TOPSIS, VIKOR, and WASPAS. Erdin [32] proposed a MCDM model based on Entropy and TOPSIS methods under Interval Valued Pythagorean Fuzzy sets to solve a hydrogen production facility location selection problem. The model is applied to the cities in the Black Sea region of Turkey. Nie et al. [33] incorporated Interval neutrosophic sets into the WASPAS technique to create a fuzzy MCDM model to solve a solar-wind power plant location selection problem. Sensitivity analysis and comparative analysis are performed to verify the performance of the proposed model.

In this research, the aim is to develop an MCDM model to determine the optimal supplier evaluation and selection process under fuzzy decision-making environment in Vietnam. Fuzzy AHP and WASPAS methods are utilized to calculate the criteria weights and the ranking of the potential suppliers.

3 Methodology

3.1 Research Development

A Fuzzy Multi-Citieria Decision Model (F-MCDM) model by using FAHP and WASPAS in order to decide suitable supplier in garment industry. Three main steps are involved shown in Fig. 2.

Step 1: From the literature review and experts' opinions, all of the criteria and sub-crtieria which are used to determine the supplier selection process are identified and listed.

Step 2: FAHP is then applied in order to determine the ranking of importance for each identified criteria and sub-criteria based on literature review and experts' opinions.

Step 3: WASPAS is then applied to determine the final ranking of all alternatives based on the weights of each criteria and the scoring of each alternative. The ranking is used as evidence to support the decision-maker finalize the optimal supplier.

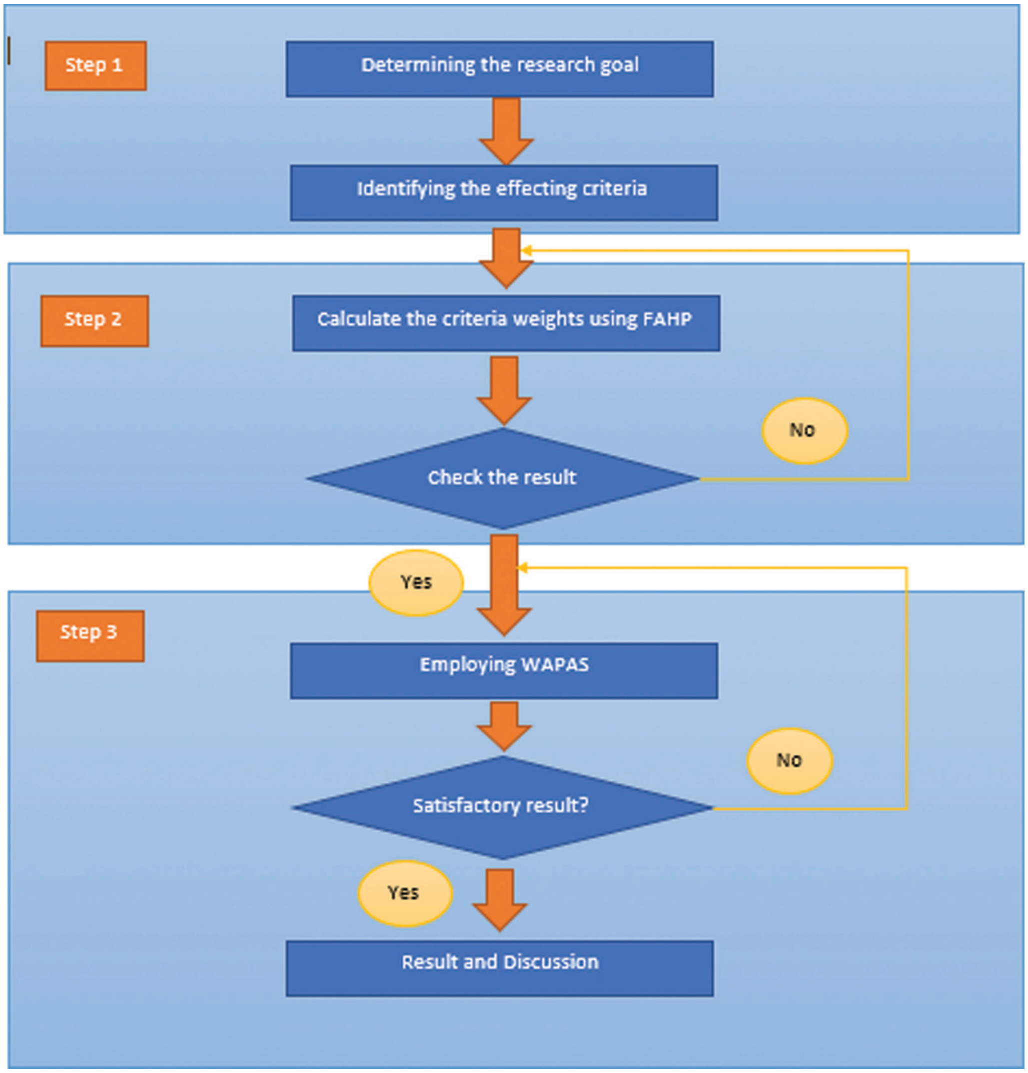

Figure 2: Research process

3.2 Fuzzy Set Theory

In order to approach the uncertainty and unclearness of human thinking and opinions in hoping to numerize such behavior, Zadeh [34] first introduced the fuzzy set theory. The theory since then has been utilized widely mainly assisting in analyzing ambiguous data, like opinionated answers, with an addition of allowing mathematical operators to be applied. Since then, the theory was able to give decision-maker a powerful tool into analyzing qualitative data. A fuzzy set is defined as a set of numeric values incorporated with a membership function where each value is assigned with a grade of membership from 0 to 1. A Triangular Fuzzy Number (TFN) denoted as $\tilde{L}$, consists of three subset values $(l_1/l_2/l_3)$, where l_1 is the minimum value, l_2 is the most common value, and l_3 is the maximum value. A TFN membership is displayed in Fig. 3. For every TFN defined as $\tilde{L}$, each value of the triplet for the membership function is between [0, 1] and can be calculated shown in Eq. (1).

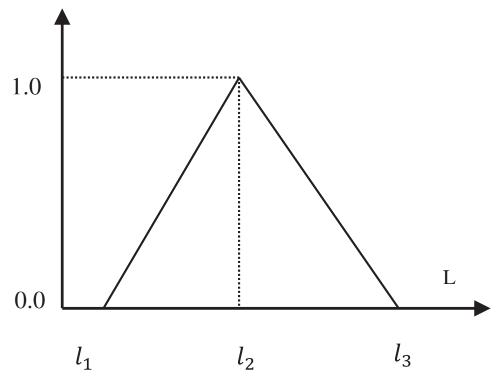

Figure 3: A Triangular fuzzy number

The membership function of $\tilde{L}$ is defined as:

$$\mu(x|\tilde{L}) = \begin{cases} 0, & x < l_1 \\ \dfrac{x - l_1}{l_2 - l_1}, & l_1 \le x \le l_2 \\ \dfrac{l_3 - x}{l_3 - l_2}, & l_2 \le x \le l_3 \\ 0, & x > l_3 \end{cases} \tag{1}$$

A fuzzy number can be defined by its corresponding left and right-side representation:

$$\tilde{L} = L^{l(y)},\ L^{r(y)}) = (l_1 - (l_2 - l_1)y, l_3 + (l_2 - l_3)y \tag{2}$$

With y $\in [0, 1]$

where $l(y)$ and $r(y)$ denotes the left side representation and the right-side representation of a fuzzy number, respectively.

3.3 Fuzzy Analytical Hierarchy Process (FAHP) Model

Fuzzy Analytical Hierarchy Process (FAHP) is an extension of the Analytical Hierarchy Process (AHP) that applies with the fuzzy set in order to minimize the uncertainty in a decision-making environment. We denote $X = \{x_1,\ x_2, \ldots.\ x_n\}$ be the set of numeric values and $T = \{t_1,\ t_2, \ldots t_n\}$ be the finalized target set. For each numeric value taken, an analysis of its target set is performed which Chang [35] applied with their analysis method. The values are then denoted as:

$$L^1_{t_i}, L^2_{t_i}, \ldots, L^m_{t_i}, \qquad i = 1, 2, \ldots, n \tag{3}$$

where $L^j_t (j = 1, 2, \ldots., m)$ are the TFNs

Fuzzy synthetic extent value of the i^{th} object is defined as:

$$S_i = \sum_{j=1}^{m} L^j_{t_i} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} L^j_{t_i} \right]^{-1} \tag{4}$$

The possibility that $L_1 \ge\ L_2$ is defined as:

$$V(L_1 \ge L_2) = sup_{y \ge x}\left[min\left(\mu_{L_1}(x),\right), \left(\mu_{L_2}(y)\right)\right] \tag{5}$$

where the pair (x, y) exists with $x \ge y$ and $\mu_{L_1}(x) =\ \mu_{L_2}(y)$, then we have $V(L_1 \ge L_2) = 1$.

Since L_1 and L_2 are convex fuzzy numbers, we have:

$$V(L_1 \geq L_2) = 1,\ if\ l_1 \geq l_2 \tag{6}$$

and

$$V(L_2 \geq L_1) = hgt(L_1 \cap L_2) = \mu_{L_1}(d) \tag{7}$$

where d is the ordinate of the highest intersection point D between μ_{L_1} and μ_{L_2}
With $L_1 = (p_1, q_1, r_1)$ and $L_2 = (p_2, q_2, r_2)$, the ordinate of point D is calculated by (8):

$$V(L_2 \geq L_1) = hgt(L_1 \cap L_2) = \frac{l_1 - r_2}{(q_2 - r_2) - (q_1 - p_1)} \tag{8}$$

In order to do a L_1 and L_2 comparison, we need to determine the values of $V(L_1 \geq L_2)$ and $V(L_2 \geq L_1)$.

The possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $L_i(i = 1, 2, \ldots k)$ is calculated as:

$$V(L \geq L_1, L_2, \ldots, L_t) = V[(L \geq L_1)\ and\ (L \geq L_2)\ ] \tag{9}$$

and, $(L \geq L_k)$ = min V (L $\geq L_i$), $i = 1, 2, \ldots,\ t$

Under the assumption that:

$$d'(B_i) = minV(S_i \geq S_t) \tag{10}$$

for $t\ = 1, 2, \ldots n$ and $t\#i$, the weight vector is defined as:

$$W' = (d'(B_1), d'(B_2), \ldots d'(B_n))^Z \tag{11}$$

where B_i are n elements.

The Normalized weight vectors calculated as follows:

$$W = (d(B_1), d(B_2), \ldots., d(B_n))^Z \tag{12}$$

With W is a nonfuzzy number.

The consistency of the pair-wise comparison matrices are tested using a classical consistency test utilized in all AHP processes where:

$$CR = \frac{CI}{RI} = \frac{\bar{\lambda} - n}{(n-1) \times RI} \leq 0.1 \tag{13}$$

where:

– Consistency Ratio (CR);

– Consistency Index (CI);

– Random Index (RI).

3.4 Weighted Aggregated Sum Product Assessment (WASPAS)

The Weighted Sum Model (WSM) is one of the most common and efficient multicriteria decision models used to assess multiple alternatives. First, $\boldsymbol{x}$ options and $\boldsymbol{y}$ decision criteria are defined. Secondly, $\boldsymbol{z_y}$ as the importance for the criteria and $\boldsymbol{a_{xy}}$ is the performance level for option $\boldsymbol{x}$ evaluated in criterion $\boldsymbol{y}$. Finally, the overall relative significance of alternative $\boldsymbol{b}$, denoted as $\boldsymbol{P_b^{(1)}}$, is defined [36]:

$$\boldsymbol{P_b^{(1)}} = \sum\nolimits_{y=1}^{n} \overline{a}_{xy} z_y \tag{14}$$

where the linear normalization for each initial criteria value are calculated as follows:

$$\overline{a}_{xy} = \frac{a_{xy}}{max_x a_{xy}} \tag{15}$$

if $max_x a_{xy}$ value is preferable or

$$\overline{a}_{xy} = \frac{min_x a_{xy}}{a_{xy}} \tag{16}$$

if $min_{xy} \overline{a}_{xy}$ value is not preferable.

The Weight Product Model (WPM) is another model that is commonly utilized for assessing multiple options using the total relative significance of option b, denoted as $P_b^{(2)}$. It is defined as follows [36]:

$$P_b^{(2)} = \prod_{y=1}^{n} \left(\overline{a}_{xy}\right)^{zy} \tag{17}$$

The weights of total relative importance are then equally divided between the WSM and WPM results for a total score in order to combine both models in evaluating further the significance of options:

$$P_b = 0.5 P_b^{(1)} + 0.5 P_b^{(2)} \tag{18}$$

The results shown from the WSM and WPM models can further be examined in order to adapt suitably by looking at the environment that is required based on the research above and the improvement of the accuracy and effectiveness in decision making. The modification of such results is called the Weighted Aggregate Sum Product Assessment model and this model is used to rank the alternatives in this research. If the decision maker has no preference, λ is equal to 0.5.

$$P_b = \lambda \sum_{y=1}^{n} \overline{a}_{xy} z_y + (1 - \lambda) \prod_{y=1}^{n} \left(\overline{a}_{xy}\right)^{z_y} \tag{19}$$

4 Numerical Example

In the first months of 2021, Vietnamese garment enterprises received optimistic signals when many orders increased. However, in the context of the complicated and unpredictable COVID-19 epidemic worldwide, Vietnamese enterprises are also facing internal challenges. Standing in the top 3 of the world's leading textile and garment exporting countries, the value brought by Vietnam's Textile and Garment Industry is very low, with a profit margin of about 5% to 10%. The existence mentioned above is because Vietnam have not been able to proactively source raw materials and auxiliary materials in the country and depend on foreign imports. Therefore, when there is a supply problem, the production and business activities of enterprises are negatively affected. For sustainable development, forcing textile and garment units to invest and actively seek alternative sources of supply.

Therefore, the research evaluates the potential of suppliers through a Multi-Criteria Decision Making (MCDM) process that determines the potential suppliers in garment industry. The process used the FAHP and WASPAS as mentioned. To apply the proposed models, 10 supplier are taken into consideration (Tab. 1).

Table 1: Ten potential suppliers in garment industry

No	Company name	Symbol
1	TIC–QA Certification Co., Ltd	RE001
2	Vinh Thuan Joint Stock Company	RE002
3	Hoang Kim Co., Ltd	RE003
4	Van Nam Co., Ltd	RE004
5	Thi Hien Joint Stock Company	RE005
6	Kim Hai Commercial and Production Co., Ltd	RE006
7	Trong Tin Commercial and Production Co., Ltd	RE007
8	Ni Uyn Joint Stock Company	RE008
9	Cha Uyn Commercial and Production Co., Ltd	RE009
10	VT Commercial and Production Co., Ltd	RE010

To determine the possible evaluation in choosing the best supplier, 15 standards are chosen. (Tab. 2)

Table 2: All sub-criteria affecting to decision processes

No	Criteria	Symbol
1	Cost	CRE01
2	Quality	CRE02
3	Service level	CRE03
4	After-sales services	CRE04
5	Before-sales services	CRE05
6	Environmental and ethical factors	CRE06
7	Geographical location	CRE07
8	Logistics cost	CRE08
9	Market reputation	CRE09
10	Performance history	CRE010
11	Political stability	CRE011
12	Product quality	CRE012
13	Purchasing price	CRE013
14	Technical capability	CRE014
15	Trade Certified	CRE015

All standards and criteria were determined by 12 experts. The decision-making procedure is then initiated in order to analyze the given data.

Firstly, a fuzzy comparison matrix for all criteria from FAHP model are shown in Tab. 3:

Table 3: Fuzzy comparison matrices for criteria

	CREM1	CREM2	CREM3	CREM4
CREM1	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1/2, 1/3, 1/4)
CREM2	(1/2, 1/3, 1/4)	(1, 1, 1)	(1, 1, 1)	(1/3, 1/4, 1/5)
CREM3	(1/3, 1/2, 1)	(1/3, 1/4, 1/5)	(1, 1, 1)	(1/3, 1/4, 1/5)
CREM4	(4, 3, 2)	(1, 1, 1)	(5, 4, 3)	(1, 1, 1)

During the defuzzification process, the coefficients values are selected with α = 0.5 and β = 0.5. In it, α represents the uncertain environment, β represents the attitude of the evaluator is fair and unbiased [37].

$g_{0.5,\ 0.5}\left(\overline{a_{CREM1,\ CREM2}}\right) = [(0.5 \times 2.5) + (1 - 0.5) \times 4] = 3.25$

$f_{0.5}(L_{\ CREM1,\ CREM2}) = (3.25 - 3) \times 0.5 + 3 = 3.125$

$f_{0.5}(U_{\ CREM1,\ CREM2}) = 5 - (5 - 3.25) \times 0.5 = 4.125$

$g_{0.5,\ 0.5}\left(\overline{a_{MAIN2,\ CREM2}}\right) = 1/3$

The remaining calculation are similar to the above, as well as the fuzzy number priority point, the real number priority when comparing the main criteria pairs presented in Tab. 4.

Table 4: Real number priority

	TECFA	MAIN2	EFFPO	ESOCF
TECFA	1	1	2	1/3
TRAEN	1/3	1	1	1/4
EFFPO	1/2	1/4	1	1/4
ESOCF	3	1	4	1

To calculate the maximum individual value as following:

$YZ1 = (1 \times 1 \times 2 \times 1/3)^{1/4} = 0.9036$

$YZ2 = (1/3 \times 1 \times 1 \times 1/4)^{1/4} = 0.5373$

$YZ3 = (1/2 \times 1/4 \times 1 \times 1/4)^{1/4} = 0.4204$

$YZ4 = (3 \times 1 \times 4 \times 1)^{1/4} = 1.8612$

$\sum YZ = QA1 + QA2 + QA3 + QA4 = 3.7225$

$$\omega_1 = \frac{0.9036}{3.7225} = 0.24$$

$$\omega_2 = \frac{0.5373}{3.7225} = 0.14$$

$$\omega_3 = \frac{0.4204}{3.7225} = 0.11$$

$$\omega_4 = \frac{1.8612}{3.7225} = 0.50$$

$$\begin{bmatrix} 1 & 1 & 2 & 1/3 \\ 1/3 & 1 & 1 & 1/4 \\ 1/2 & 1/4 & 1 & 1/4 \\ 3 & 1 & 4 & 1 \end{bmatrix} \times \begin{bmatrix} 0.24 \\ 0.14 \\ 0.11 \\ 0.50 \end{bmatrix} = \begin{bmatrix} 0.77 \\ 0.46 \\ 0.39 \\ 1.8 \end{bmatrix}$$

Since the number of criteria is 4, we get n = 4, λ_{max} and CI are calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0092$$

For CR, with n = 4 we get RI = 0.9 as pre-determined from an AHP study.

$$CR = \frac{CI}{RI} = \frac{0.0092}{0.9} = 0.0101$$

We have CR = 0.0101 ≤ 0.1, so the pairwise comparison data is consistent and does not need to be re-evaluated.

The calculated weight of each sub criteria using FAHP is shown in Tab. 5.

Table 5: Weight of all sub-criteria

No	Sub-criteria	Symbol	Weight
1	Cost	CRE01	0.0708
2	Quality	CRE02	0.0694
3	Service level	CRE03	0.0876
4	After-sales services	CRE04	0.0756
5	Before-sales services	CRE05	0.1020
6	Environmental and ethical factors	CRE06	0.0589
7	Geographical location	CRE07	0.0507
8	Logistics cost	CRE08	0.0699
9	Market reputation	CRE09	0.0777
10	Performance history	CRE010	0.0565
11	Political stability	CRE011	0.0459
12	Product quality	CRE012	0.0863
13	Purchasing price	CRE013	0.0496
14	Technical capability	CRE014	0.0446
15	Trade certified	CRE015	0.0545

WASPAS model is applied for ranking all potential suppliers in final stages. The normalized matrix and normalized weighted matrix are show in Tabs. 6 and 7 below.

Table 6: Normalized matrix

	W001	W002	W003	W004	W005	W006	W007	W008	W009	W010
CRE01	1.0000	1.0000	1.0000	0.8889	1.0000	0.8889	0.7778	0.6667	1.0000	1.0000
CRE02	0.6667	0.7778	1.0000	0.6667	0.7778	1.0000	0.7778	1.0000	1.0000	0.6667
CRE03	0.7778	0.7778	0.7778	0.7778	0.5556	0.6667	0.8889	1.0000	1.0000	0.8889
CRE04	1.0000	0.7778	0.7778	0.8889	0.8889	1.0000	0.7778	0.8889	1.0000	0.8889
CRE05	1.0000	0.7778	0.7778	0.7778	1.0000	1.0000	0.8889	0.7778	0.8889	1.0000
CRE06	0.8750	1.0000	0.8750	1.0000	1.0000	0.7500	1.0000	1.0000	0.8750	0.8750
CRE07	0.6667	0.7778	0.7778	0.8889	1.0000	1.0000	0.7778	0.6667	1.0000	1.0000
CRE08	0.6667	0.7778	0.5556	0.6667	0.8889	1.0000	1.0000	0.8889	1.0000	0.7778
CRE09	0.7778	0.8889	0.8889	1.0000	0.7778	0.7778	0.8889	1.0000	0.8889	1.0000
CRE010	0.8889	0.7778	1.0000	0.7778	0.7778	0.7778	1.0000	0.8889	0.8889	0.7778
CRE011	0.4444	0.8889	0.7778	0.8889	0.8889	0.6667	0.8889	0.8889	1.0000	1.0000
CRE012	0.6667	1.0000	0.6667	0.7778	1.0000	0.7778	0.8889	0.7778	1.0000	0.6667
CRE013	0.5556	0.7778	0.5556	0.6667	0.8889	1.0000	0.7778	1.0000	0.7778	0.7778
CRE015	1.0000	0.8889	1.0000	0.7778	0.7778	0.8889	1.0000	0.8889	1.0000	0.8889
CRE014	0.7778	0.7778	1.0000	0.6667	0.5556	0.6667	0.8889	1.0000	1.0000	0.8889

Table 7: Normalized weighted matrix

	W001	W002	W003	W004	W005	W006	W007	W008	W009	W010
CRE01	0.0708	0.0708	0.0708	0.0629	0.0708	0.0629	0.0551	0.0472	0.0708	0.0708
CRE02	0.0463	0.0540	0.0694	0.0463	0.0540	0.0694	0.0540	0.0694	0.0694	0.0463
CRE03	0.0681	0.0681	0.0681	0.0681	0.0487	0.0584	0.0779	0.0876	0.0876	0.0779
CRE04	0.0756	0.0588	0.0588	0.0672	0.0672	0.0756	0.0588	0.0672	0.0756	0.0672
CRE05	0.1020	0.0793	0.0793	0.0793	0.1020	0.1020	0.0907	0.0793	0.0907	0.1020
CRE06	0.0515	0.0589	0.0515	0.0589	0.0589	0.0442	0.0589	0.0589	0.0515	0.0515
CRE07	0.0338	0.0394	0.0394	0.0451	0.0507	0.0507	0.0394	0.0338	0.0507	0.0507
CRE08	0.0466	0.0544	0.0388	0.0466	0.0621	0.0699	0.0699	0.0621	0.0699	0.0544
CRE09	0.0604	0.0691	0.0691	0.0777	0.0604	0.0604	0.0691	0.0777	0.0691	0.0777
CRE010	0.0502	0.0439	0.0565	0.0439	0.0439	0.0439	0.0565	0.0502	0.0502	0.0439
CRE011	0.0204	0.0408	0.0357	0.0408	0.0408	0.0306	0.0408	0.0408	0.0459	0.0459
CRE012	0.0575	0.0863	0.0575	0.0671	0.0863	0.0671	0.0767	0.0671	0.0863	0.0575
CRE013	0.0276	0.0386	0.0276	0.0331	0.0441	0.0496	0.0386	0.0496	0.0386	0.0386
CRE015	0.0446	0.0396	0.0446	0.0347	0.0347	0.0396	0.0446	0.0396	0.0446	0.0396
CRE014	0.0424	0.0424	0.0545	0.0363	0.0303	0.0363	0.0484	0.0545	0.0545	0.0484

Table 8: Exponentially weighted matrix

	RE001	RE002	RE003	RE004	RE005	RE006	RE007	RE008	RE009	RE010
CRE01	1.0000	1.0000	1.0000	0.9917	1.0000	0.9917	0.9824	0.9717	1.0000	1.0000
CRE02	0.9723	0.9827	1.0000	0.9723	0.9827	1.0000	0.9827	1.0000	1.0000	0.9723
CRE03	0.9782	0.9782	0.9782	0.9782	0.9498	0.9651	0.9897	1.0000	1.0000	0.9897
CRE04	1.0000	0.9812	0.9812	0.9911	0.9911	1.0000	0.9812	0.9911	1.0000	0.9911
CRE05	1.0000	0.9747	0.9747	0.9747	1.0000	1.0000	0.9881	0.9747	0.9881	1.0000
CRE06	0.9922	1.0000	0.9922	1.0000	1.0000	0.9832	1.0000	1.0000	0.9922	0.9922
CRE07	0.9797	0.9873	0.9873	0.9940	1.0000	1.0000	0.9873	0.9797	1.0000	1.0000
CRE08	0.9721	0.9826	0.9597	0.9721	0.9918	1.0000	1.0000	0.9918	1.0000	0.9826
CRE09	0.9807	0.9909	0.9909	1.0000	0.9807	0.9807	0.9909	1.0000	0.9909	1.0000
CRE010	0.9934	0.9859	1.0000	0.9859	0.9859	0.9859	1.0000	0.9934	0.9934	0.9859
CRE011	0.9635	0.9946	0.9885	0.9946	0.9946	0.9816	0.9946	0.9946	1.0000	1.0000
CRE012	0.9656	1.0000	0.9656	0.9785	1.0000	0.9785	0.9899	0.9785	1.0000	0.9656
CRE013	0.9713	0.9876	0.9713	0.9801	0.9942	1.0000	0.9876	1.0000	0.9876	0.9876
CRE015	1.0000	0.9948	1.0000	0.9889	0.9889	0.9948	1.0000	0.9948	1.0000	0.9948
CRE014	0.9864	0.9864	1.0000	0.9781	0.9685	0.9781	0.9936	1.0000	1.0000	0.9936

Exponentially weighted matrix is shown in Tab. 8. After applying the suitable models and evaluating all of the criteria from each experts' opinions regarding the suitable supplier in garment industry using quantitative and qualitative factors, a ranking of alternatives have been produced using MCDM tools suitable being the FAHP and WASPAS models. Tab. 9 and Fig. 4 displays the final ranking after the calculation in ascending order, which are, RE009, RE010, RE008, RE006, RE007, RE005, RE002, RE003, RE001, RE004. Therefore, Da Nang (RE009) appears to be the optimal supplier.

Table 9: Results from WASPAS model

Alternatives	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i	Ranking
RE001	0.7979	0.9511	0.8745	9
RE002	0.8445	0.9193	0.8819	7
RE003	0.8217	0.9355	0.8786	8
RE004	0.8081	0.9112	0.8596	10
RE005	0.8549	0.9251	0.8900	6
RE006	0.8608	0.9571	0.9089	4
RE007	0.8793	0.9263	0.9028	5
RE008	0.8852	0.9387	0.9119	3
RE009	0.9554	0.9881	0.9717	1
RE010	0.8725	0.9537	0.9131	2

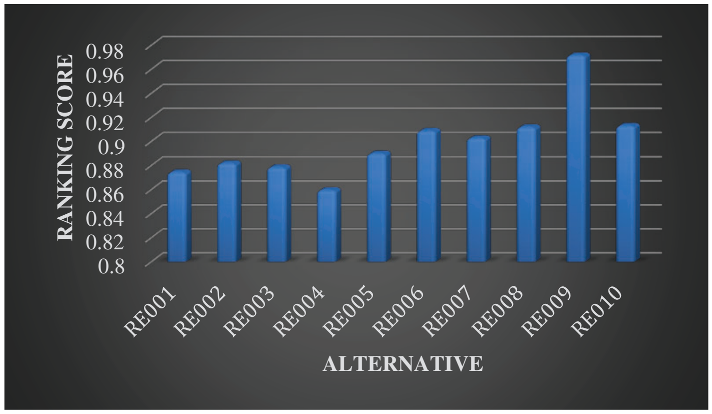

Figure 4: Final ranking from WASPAS

The complexity of the result for the model is examined using sensitivity analysis. In this case, the results of the model were re-examined in the case of the social criteria (CRE011, CRE012, CRE013, CRE014) were not considered. The results of the analyzed model using the case mentioned is shown in Fig. 5.

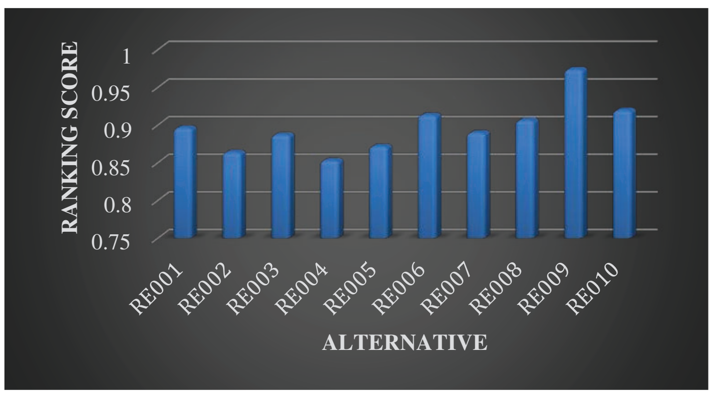

Figure 5: Ranking from WASPAS without social criteria

Although there were changes for lower ranking alternatives, the results of the sensitivity analysis concluded that RE009 as the optimal supplier followed by RE010 even when the social criteria were removed from the model. This suggested that the social criteria have small impact compared to the original result of the model, which is explained since RE009 and RE010 both have higher performance in other criteria that allowed them to be prioritized even when the social criteria are not considered. Therefore, the proposed model's result can be considered complex.

5 Conclusions

An application process applied decision making problems is the main activity that is proposed in this research regarding determining an optimal supplier in garment industry. The MCDM models are taken into consideration after a data collection phase has been conducted to analyze the data. This paper utilized the application of Fuzzy-MCDM due to the nature of the data being uncertain amongst the experts consulted. From the nature of the data, the proposed FAHP and WASPAS models are then applied to process and successfully determined the optimal supplier using 10 alternatives over a set of 4 criteria and 15 sub-criteria. The research successfully developed the highest accuracy of estimation in determining supplier in a multi-criteria framework.

A real problem of supplier ‘s assessment in garment industry is handled to examine the performance of the proposed model. By some comparative analysis and through the evidence, the stability of the Fuzzy MCDM model is also approved. The proposed model can be applied to supplier selection problems in other industries. However, as the proposed model is based on the fuzzy AHP method, the interdependency of the criteria has not been fully considered. A comparative study between the proposed model and a similar ANP-based model should also be performed in the future to further understand the interdependency of the criteria. Further studies regarding this topic can be further expanded across multiple MCDM tools that helps in determining the best alternative such as data envelopment analysis (DEA) or the decision-making trial and evaluation laboratory (DEMATEL).

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